

Californium-252 Neutron Capture and Decay
Methods for Elemental Analysis

Final Report

to

National Aeronautics and Space Agency

from

U. S. Geological Survey

Washington, D. C. 20242

April 25, 1972

(NASA-CR-127119) CALIFORNIUM-252 NEUTRON
CAPTURE AND DECAY METHODS FOR ELEMENTAL
ANALYSIS Final Report (Geological Survey)
25 Apr. 1972 32 p

N72-26578

CSCL 20H

G3/24 Unclass
33615

W-13,186

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INTRODUCTION

The following report covers the two year period from April 1970 to April 1972 during which this project was in force. The general objective of the project was to test the feasibility of using a ^{252}Cf neutron source in conjunction with a capture and/or decay gamma ray method for elemental analysis in lunar or planetary missions.

The project is a cooperative effort between the U. S. Geological Survey (F. Senftle) and Goddard Space Flight Center (J. Trombka). The work of each group was delineated so as to compliment each other. The primary responsibility of the USGS team was to work out the general problems of using a ^{252}Cf neutron source for both decay and capture gamma ray analysis in terrestrial environments. This work included the determination of the capture gamma ray spectra by neutron absorption in various metals used for the space hardware, ^{252}Cf source encapsulation materials, shielding, geometry, optimum source size for a space mission, etc. The responsibility of the GSFC team was to investigate the computer data reduction and data transmission techniques. The original plans allowed for some overlap of the primary missions of each team. The results of this investigation have led to the publication of eight scientific papers and a ninth paper is in preparation.

PROJECT OBJECTIVES

The broad objective of the project is to evaluate the radiative neutron-capture gamma-ray and decay-gamma methods of neutron activation using a californium-252 neutron source as a feasible analytical technique to be used on lunar and/or planetary missions. To develop practical operating techniques basic information was lacking in a number of areas. It was therefore desired to:

(1) Determine optimum shielding and encapsulation materials for the californium source required for a planetary mission.

(2) Compare Ge(Li) and NaI(Tl) as detectors for capture gamma rays.

(3) Determine source-to-detector geometry for optimum operation.

(4) Determine the effect of the hydrogen concentration in the environment on the spectrum obtained.

(5) Develop computer data reduction systems to increase the sensitivity and obtain the best possible analytical data.

(6) Develop both NaI(Tl) and Ge(Li) probes for possible shallow borehole analysis below the planetary or lunar surface.

Over the past two years most of these objectives have been accomplished.

THE CAPTURE GAMMA RAY SPECTRUM

When an atomic nucleus absorbs a neutron, it is raised to an excited state. De-excitation generally takes place within a fraction

1 of a millisecond by the emission of one or more radiative capture
2 gamma rays which have energies up to the binding energy of the neutron,
3 i.e. up to about 11 MeV. If the resulting nucleus is unstable, further
4 emission of decay gamma rays will take place at a later time depending
5- on the half-life of the nucleus. Both of these processes are shown in
6 Figure 1. Conventional activation analysis uses the decay gamma rays.
7 However, as the capture gamma rays are also diagnostic of the parent
8 element, they also can be used for analytical purposes. Contrary to
9 the radiative capture method, problems associated with using the decay
10- gamma method are well known and will not be discussed further.

11 Ideally, for a lunar or planetary mission it would be advantageous to
12 use a gamma ray spectrometer in both the decay and capture gamma ray
13 modes. Some elements are more easily detected by the decay method
14 while others are more easily observed by the radiative capture method.

15- Comar et al⁽¹⁾, using a reactor source of neutrons and a Ge(Li)
16 detector, have shown the advantages of using capture gamma rays for
17 the analysis of biological samples, whereas Christell and Ljunggren⁽²⁾
18 have used an isotopic source of neutrons with a NaI(Tl) detector to
19 determine iron in ores. More recently, Senftle et al⁽³⁾ and Wiggins
20- et al⁽⁴⁾ have used a ^{252}Cf as an isotopic source of neutrons with a
21 Ge(Li) detector to analyze Ni and Ti respectively in ores by the
22 capture γ ray method. In the latter four investigations, high energy
23 capture gamma rays have been used to determine a given element. For
24 space application it is desirable to use ^{252}Cf as a source of neutrons
25- because of its small size and weight.

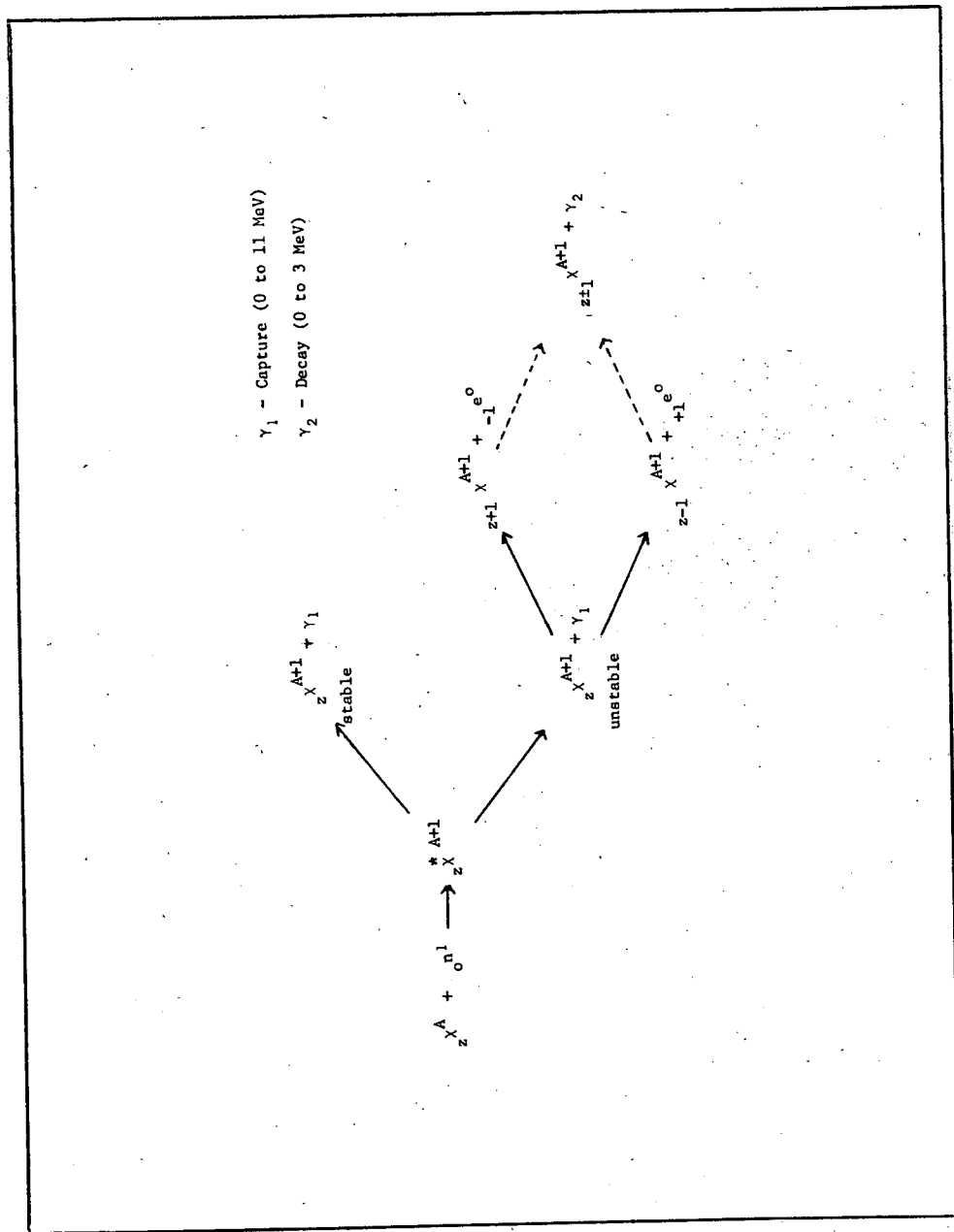


Figure 7

1 As in a reactor, radiative neutron-capture gamma rays can be
2 produced with a ^{252}Cf neutron source by placing the target (sample)
3 either close to the source (internal geometry) or in a neutron beam
4 extracted from a massive shield surrounding the ^{252}Cf (external
5- geometry). As pointed out by Garbrah and Whittey⁽⁵⁾ the latter
6 technique is generally most desirable when using a reactor.
7 Practically, however, a ^{252}Cf source would have to be in the multigram
8 weight range to furnish enough neutrons to produce a beam of
9 sufficiently high flux for this purpose. ^{252}Cf sources of this size
10- are not common and are difficult to manipulate safely except in
11 special laboratory facilities. To use a smaller ^{252}Cf source of 500
12 μg or less, however, one must use an internal geometry because of the
13 low initial neutron yield. Several variations of an internal geometry
14 can be constructed, but, in general, the sample and ^{252}Cf source are
15- placed in close proximity, and are surrounded with a moderator. The
16 Ge(Li) detector is placed at some distance commensurate with the
17 protection of the crystal from neutron radiation damage.

18 Under these conditions a number of background effects present
19 themselves which interfere with the high-energy capture gamma-ray
20- spectra:

21 (a) The material from which the ^{252}Cf capsule is fabricated emits
22 a capture gamma-ray spectrum.

23 (b) The moderator surrounding the source and sample emits a
24 characteristic capture gamma-ray spectrum.
25-

1 (c) Although in a relatively low neutron flux, the rather massive
2 hardware associated with the detector will emit a characteristic
3 capture gamma-ray spectrum.

4 (d) ^{252}Cf is a fission-type neutron source, and hence, there will
5 be a substantial continuum underlying any capture gamma-ray spectrum.

6 By analogy with a reactor and as suggested by Hammermesh and
7 Hummel⁽⁶⁾ these background interferences can in theory be appropriately
8 subtracted out. However, to do this one must count over long periods
9 of time to obtain adequate counting statistics. Such long counting
10 times are not always practical and thus, it is desirable to reduce
11 these effects to a minimum by proper choice of materials, geometry,
12 etc.

13 INTERFERENCES FROM SOURCE ENCAPSULATION MATERIALS

14
15 It is clear that the radiative capture gamma rays from the
16 materials in the source capsule will be superimposed on the background
17 spectra. Thus, the choice of encapsulation material will be important
18 to minimize background interference from the source. Interference
19 parameters for thirty-eight elements have been calculated (Senftle et
20 al, ref. 7), most of which are important as construction materials.
21 It was concluded that zirconium or a high-zirconium alloy would be
22 most suitable for source encapsulation and would contribute least to
23 the background. As a result of this study the U. S. Atomic Energy
24 Commission was asked to supply two californium neutron sources of
25

1 about 100 μ g, one encapsulated in the usual stainless steel capsule,
2 the other in a Zircaloy-2 capsule. The two sources were carefully
3 compared in an oil moderator (Philbin et al, ref. 8). The iron,
4 chromium, and nickel peaks in the spectrum of the stainless steel
5-- source were absent in the Zircaloy-2 clad source. The background of
6 the Zircaloy-2 source was significantly lower above 6 MeV. Although
7 there was a definite improvement in the high energy part of the
8 spectrum, the background due to the fission gamma rays from the
9 californium dominated the background spectrum below 6 MeV. For most
10-- capture-gamma-ray analyses Zircaloy-2 is the best material to be used
11 for source encapsulation.

12 INTERFERENCE FROM THE EXTERNAL MODERATOR

13
14 The neutrons emitted from californium range from about 0.2 MeV to
15-- 14 MeV, but the energy distribution peaks at about 1 MeV with the
16 overall average energy being 2.3 MeV. Generally, the probability of
17 neutron capture (the cross section) increases as the energy of the
18 neutron decreases. Therefore, to obtain maximum neutron capture the
19 average neutron energy must be reduced by scattering in a low-Z
20-- medium of proper thickness generally interposed between the source and
21 the sample. Of course this scattering material or moderator will also
22 be a source of gamma radiation and will tend to interfere with the
23 sample spectrum. Hydrogen is the best moderator and yields a strong
24 capture gamma ray at 2.22 MeV. It was initially thought that an
25-- organic moderator such as polyethylene could be used to reduce the

1 energy and scatter the neutrons into the lunar surface. Although the
2 hydrogen in the polyethylene serves as a moderator, the carbon and
3 oxygen will contribute their own spectrum and will also be a source of
4 background interference. To determine the general effect of these
5 elements on the continuum the Zircaloy-2 clad source was suspended
6 successively in a tank of oil (carbon) and then in a tank of water
7 (oxygen). Figure 2 shows the resulting spectra. The background is
8 higher in oil in the region of the full, single and double escape peaks
9 of carbon. Likewise, in water the background is higher in the vicinity
10 of the oxygen peaks. The copper and iron peaks are due to impurities
11 in the water. In both cases, but not shown in the figure, the back-
12 ground near 2 MeV and at lower energy is increased by the presence of
13 the hydrogen peak at 2.22 MeV. In addition to the hydrogen interference
14 one can expect to obtain some interference in the spectrum from 3.50
15 MeV to 6.25 MeV due to carbon and oxygen, if an organic moderator is
16 used on the lunar surface. These interferences can probably be
17 minimized by computer techniques (discussed below).

18 Other materials such as ZrH_2 , and, ammonium metatungstate were
19 also tested.

20 The hydrogen and tungsten content, and the high solubility of
21 ammonium metatungstate suggest that this salt may make a good neutron-
22 gamma shield for ^{252}Cf . Comparative attenuation experiments with a
23 saturated aqueous solution and pure water show that the ammonium
24 metatungstate solution is a significantly better shielding material for
25 gamma rays and slow neutrons, and is also better than water for fast

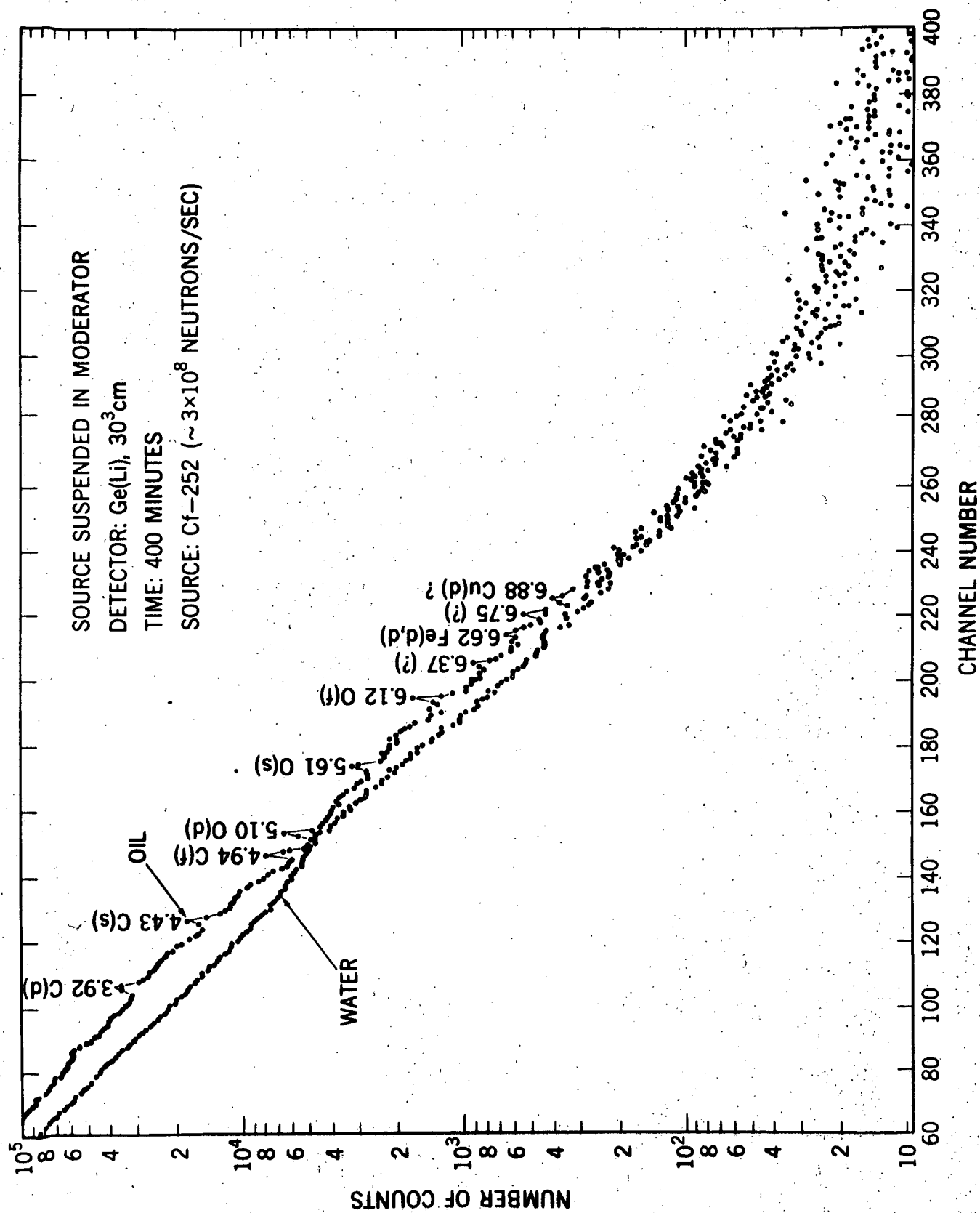


Figure 2

1 neutrons. ^{252}Cf sources of less than 500 μg , a shield consisting of a
2 thick paste of ammonium metatungstate was found to be useful as a
3 shielding material in place of a saturated solution to reduce the
4 hazard in case of container leakage. A detailed study of this report
5 has been published (Senftle and Philbin, ref. 9).

6 INTERFERENCES FROM THE DETECTOR HARDWARE

7
8 To obtain the best counting geometry it will be necessary to
9 place the detector as close as possible to the sample. It is clear
10 that the detector and its associated hardware will thus necessarily be
11 exposed to neutrons. Neutrons captured by the detector and hardware
12 will be a source of background capture gamma rays. Using a 125 μg
13 ^{252}Cf source, various thicknesses of water, oil or paraffin moderator
14 were used to test the magnitude of this source of background inter-
15 ference. Even with 26 inches of oil moderator between the source and
16 detector a substantial background was observed. To determine how much
17 of this was due to slow neutron interaction with the hardware, the
18 Ge(Li) detector and its associated liquid nitrogen reservoir were
19 completely enclosed with 3 inches of Borax to reduce the slow neutron
20 flux. Figure 3 shows a comparison of the background continuum with
21 and without the protective borax shield. While this source of
22 interference is not serious, it is significant even with this substan-
23 tial amount of moderator. It is certainly desirable to bring the
24 detector closer to the source to improve the geometry, and under these
25 conditions the hardware interference will become more acute.

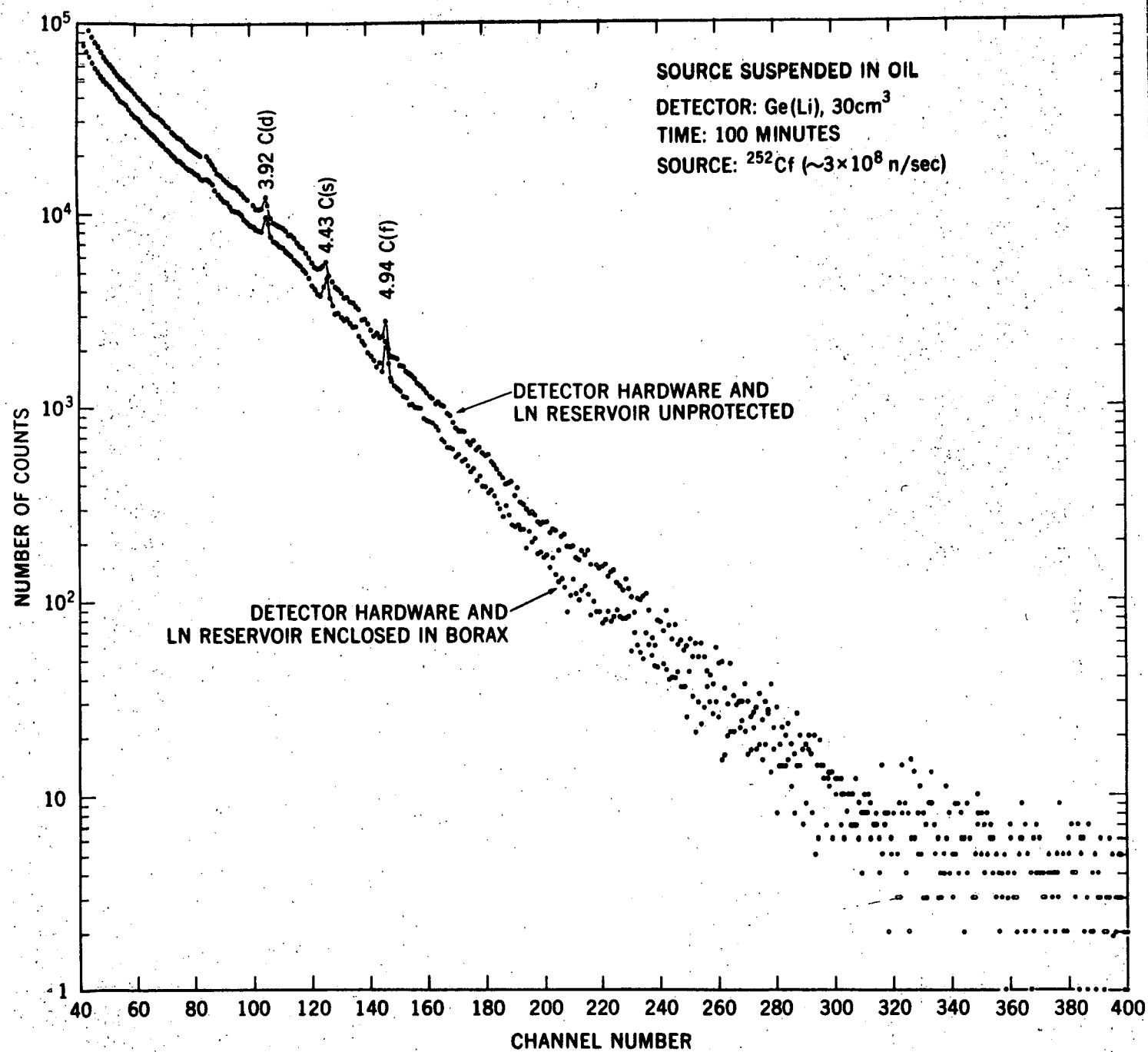


Figure 3

12

1 To minimize this effect for smaller source-to-detector distances
2 one can (a) use a smaller ^{252}Cf source, (b) specially construct all
3 hardware with low yield capture gamma ray elements^(7,8), and (c)
4 enclose the detector and its associated hardware with a light weight
5 slow neutron shielding material such as boron. Laboratory experiments
6 with powered boron and spectra taken of about 30 elements indicate
7 that a thin boron coating on the outside of the detector hardware
8 package will significantly reduce the interference. In addition, if
9 Zircaloy-2 can be used to replace aluminum and stainless steel a
10 further reduction can be achieved.

11 INTERFERENCES FROM ^{252}Cf FISSION GAMMA RAYS

12
13 Unlike other isotopic neutron sources, ^{252}Cf is a fission source
14 and emits its own fission gamma ray continuum which is itself a source
15 of interference. This can be minimized by use of a shadow shield
16 between the source and detector. Experiments were made with various
17 shadow shields including uranium and lead. Although uranium has the
18 higher density, its natural gamma emission is high, and was not as
19 good as lead for this purpose. Figure 4 shows the effect of using a
20 $3/4 \times 1-1/2 \times 4$ inch lead shadow shield. This shield substantially
21 reduced both the fission gamma radiation. The fission gamma rays are
22 perhaps the most serious source of interference when using a ^{252}Cf
23 neutron source. If a point source is used these gamma rays can be
24 substantially reduced with a shadow shield. However, if a distributed
25 or broad source is used these gamma rays may be a serious source of

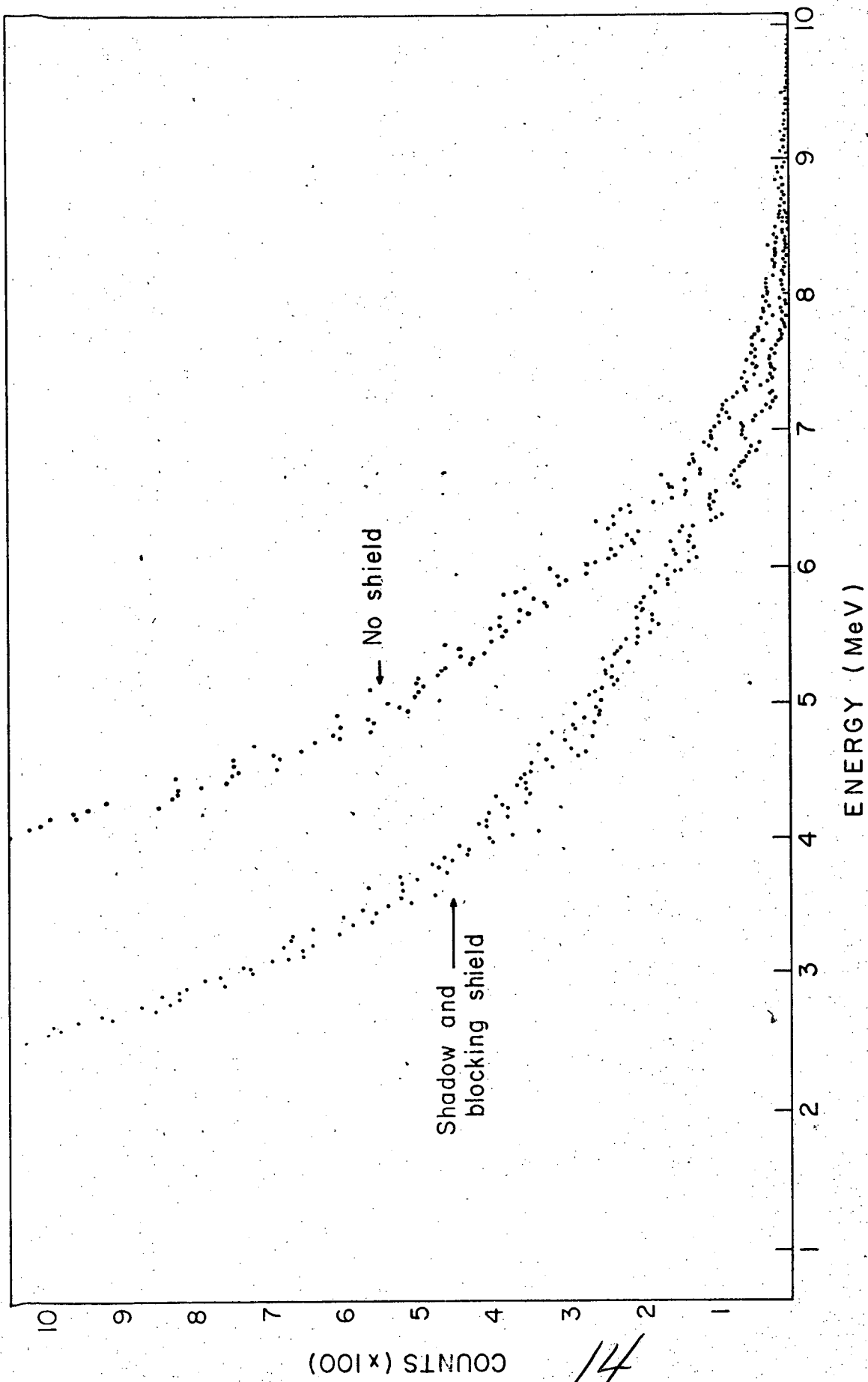


Figure 4

1 interference.

2 THE SOURCE-TO-DETECTOR DISTANCE

3
4 To determine the response of the detector with the source-to-
5- detector distance, preliminary experiments were made with a sample of
6 titanium ore (~8 lbs) in which the ^{252}Cf source was placed centrally
7 within the ore sample. The sample and source were immersed in a water
8 tank and the Ge(Li) detector was placed in a fixed position just
9 outside the tank. The source-sample assembly was arranged so that it
10- could be moved with respect to the detector. Using the double escape
11 peak of titanium at 5.74 MeV, the detector response was measured as a
12 function of source-to-detector distance as shown in Figure 5 for five
13 ^{252}Cf sources from 1 μg to 100 μg . Using the 20 μg and 100 μg sources
14 optimum distances of 16 and 20 inches, respectively, were found.
15- Experiments showed that the sharp drop in counting rate as the source-
16 sample assembly was moved closer to the detector was due to electronic
17 blocking of the detector by low energy gamma rays from both the source
18 and the moderator (mostly hydrogen). By placing a 0.5 inch thick
19 piece of lead in front of the detector the dashed curve in Figure 5 was
20- obtained. Blocking of the detector was reduced so that the source-
21 sample assembly could be brought closer to the detector before the
22 counting rate again started to drop. The resulting improvement of the
23 geometry also resulted in enhancement of the 5.74 MeV peak to an
24 optimum value at a source-to-detector distance of 17 inches. Experi-
25- ments with smaller sources confirmed this explanation. Thus, the

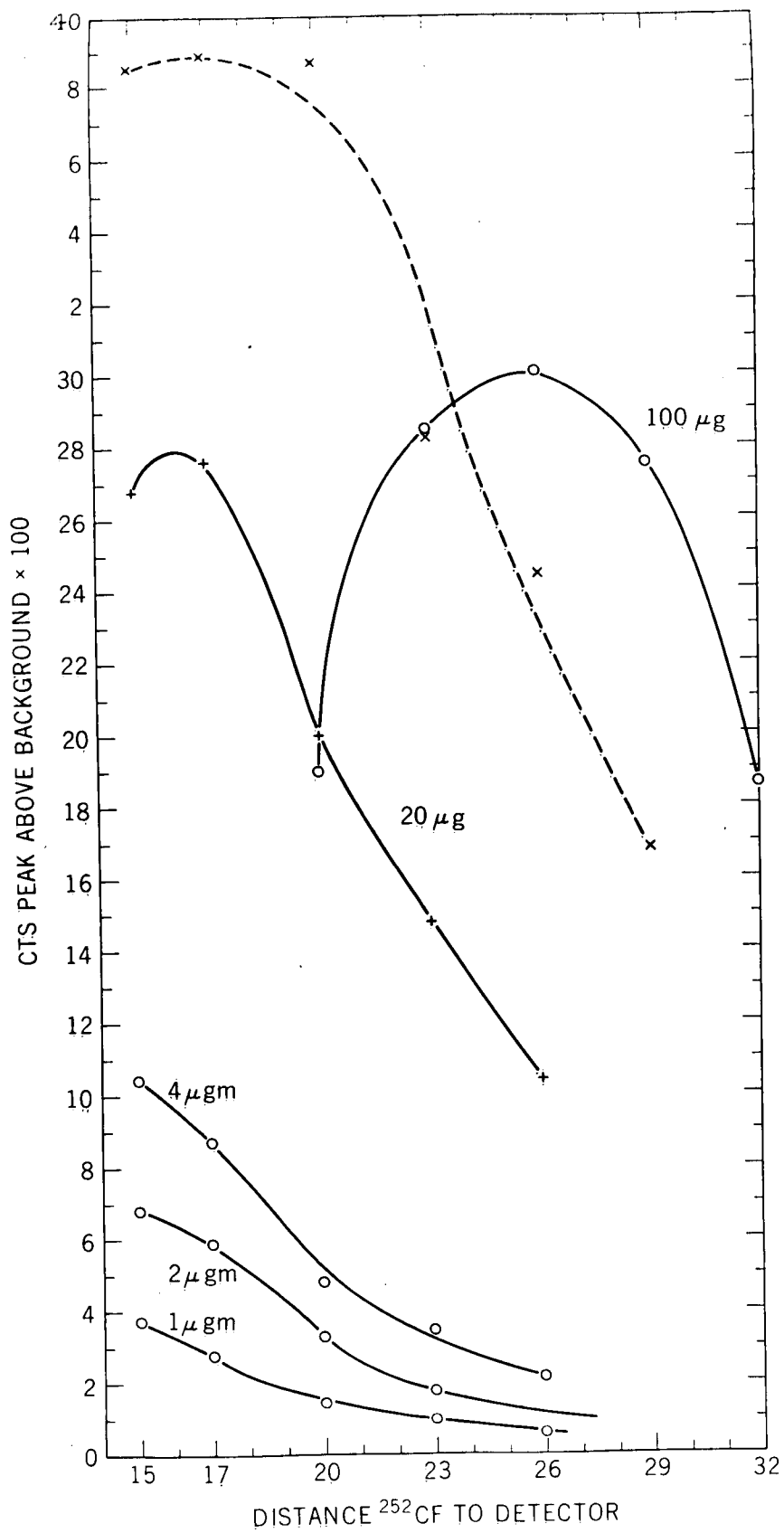


Figure 5

16

1 optimum source-to-detector distance is a function of the size of the
2 source used.

3 The above experiments were repeated with a NaI(Tl) probe in the
4 USGS Borehole Test Facility. The ^{252}Cf source was lowered down a
5- borehole surrounded with lowgrade (~1%) nickel ore to a fixed position.
6 The NaI(Tl) detector was then dropped stepwise toward the source, and
7 counts taken in a window encompassing the 8.489 MeV single escape peak
8 of nickel. Figure 6 shows how the optimum source-to-detector distance
9 and height of the nickel peak vary with strength of ^{252}Cf source.
10- Considering the difficulties in handling large sources, the data
11 suggests that sources larger than 50 μg may not be warranted for
12 capture gamma ray analysis.

13 SAMPLE POSITION

14
15- If one fixes the source-to-detector spacing and assuming an
16 infinite homogeneous medium, what is the position of the sample with
17 respect to the detector? The sample immediately around the source
18 receives the highest flux of neutrons of all energies, but the sample
19 an inch or two from the source receives the highest thermal neutron
20- flux. However, because of the absorption of the emitted gamma rays
21 and the relatively poor geometry a sample closer to the detector,
22 although it receives a lower neutron flux, may contribute proportion-
23 atly more gamma rays to the observed spectrum. To determine the
24 position of the sample for high energy capture gamma rays a probe in
25- which the ^{252}Cf was rigidly fixed with respect to the detector was

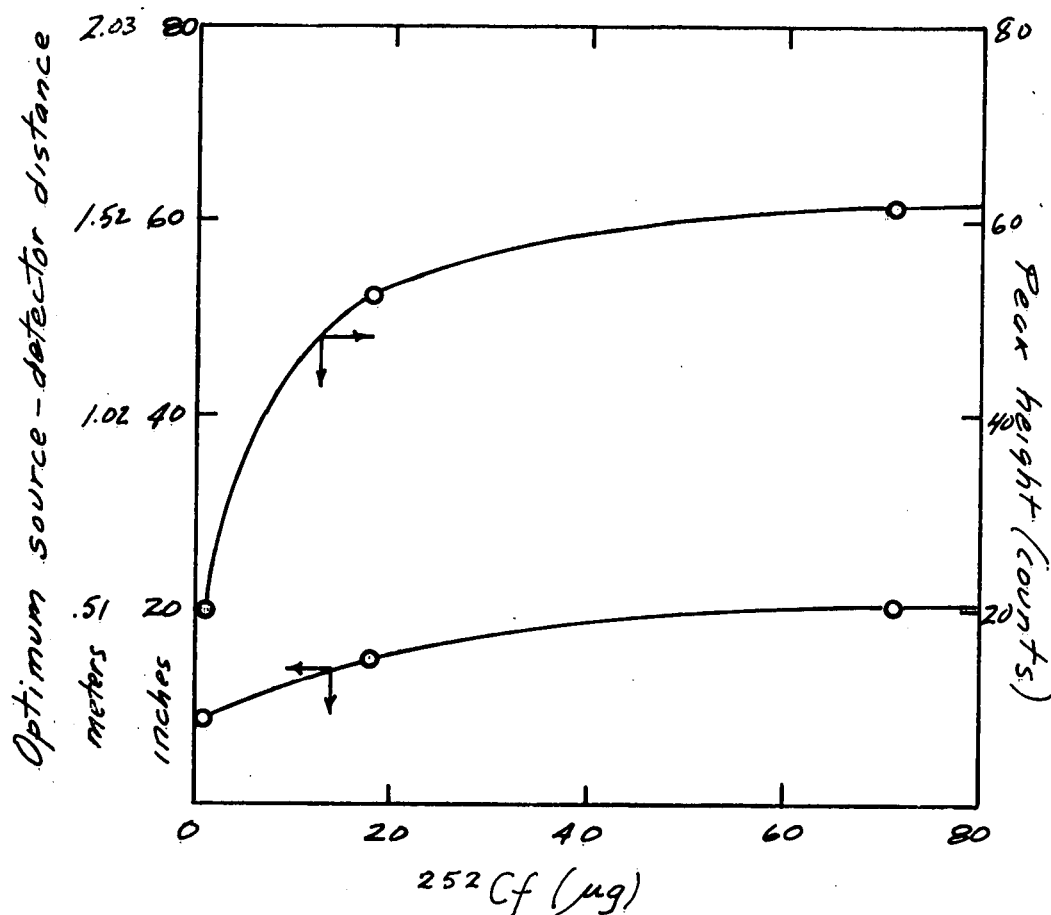


Figure 6 - The optimum source-detector distance and the height of the 8489 keV single escape peak of nickel at this distance, for a 3 x 3 inch NaI(Tl) crystal in a borehole configuration as a function of the strength of the ^{252}Cf .

1 used. Nominally 1 and 20 μg ^{252}Cf sources were used with both NaI(Tl)
2 and Ge(Li) detectors. A half inch thick layer of nickel powder was
3 sandwiched between thick layers of damp sand in the USGS Borehole
4 Facility. The probe was lowered a few inches at a time down the
5- borehole so that the source approached and passed by the nickel layer.
6 Measurements were made of the single and double escape peaks of nickel
7 at 8.489 and 7.978 MeV respectively. With a 1 μgm source it was found
8 that the sample was 3/4 of the distance from the source to the detector
9 when the source-to-detector distance was 16" regardless of the type of
10- detector used. When dry sand was used the sample was about 2" closer
11 to the detector.

12 HARDWARE CONFIGURATION

13
14 In order to use the neutron capture gamma ray method for
15- elemental analysis on a planetary mission, the system must be construc-
16- ted (a) with the ^{252}Cf source and detector as separate units which can
17 be deployed subsequent to landing or (b) the source and detector can be
18 rigidly mounted with respect to each other. Initial thinking favored
19 system (a) in order to remove the ^{252}Cf source from close proximity to
20- the NaI(Tl) crystal. However, from the experiments performed during
21 the past year it is now clear that system (b) must be given serious
22 consideration. If the ^{252}Cf is to be driven a few inches below the
23 surface it would be extremely difficult to shadow shield the neutron
24 source using system (a). In addition, if the source and detector are
25- rigidly mounted as a probe, which would be driven a few inches into

1 the ground, the geometry would be fixed and could be calibrated with
2 greater ease.

3 For lunar exploration and possibly for future planetary work, it
4 is desirable to have the capability of logging a shallow hole for a
5 variety of elements. Thus, several probes have been built in the
6 laboratory using both NaI(Tl) and Ge(Li) detectors and a 100 μg ^{252}Cf
7 source. As determined in the other laboratory experiments, it was
8 found that in order to keep the counter from blocking and also to
9 prevent activation of the crystal, a 32 inch separation was needed
10 between the source and detector. However, based on the experiments
11 with a 1 μg ^{252}Cf source and a NaI(Tl) detector, a prototype probe
12 using a 10 inch separation between detector and source has been
13 constructed and successfully operated.

14 It is felt that experiments similar to those described above
15 should be tried in a vacuum and high pressure gas environment using
16 both NaI(Tl) and Ge(Li) detectors. Such experiments will require
17 sealed detectors. Because of the liquid nitrogen cryogen needed for
18 the Ge(Li) detector, it is not possible to operate such a detector in
19 a vacuum; the constant low temperature is maintained by the latent heat
20 of vaporization of the liquid nitrogen which must be vented. It
21 occurred to us that to use the latent heat of melting of some substance
22 might be used which would preclude the need to vent the cryostat. Such
23 a probe has been built and tests have been quite successful. The
24 details of this work have been prepared as a short paper⁽¹¹⁾. This
25 probe will allow us to test the Ge(Li) detector in a vacuum as well as

1 down boreholes.

2 DATA REDUCTION

3
4 During the proposal phase of the project it was decided that the
5 USGS team would work out the laboratory development and field testing
6 of the technique and that the GSFC team would handle the data reduction
7 and transmission methods. It soon became apparent that some overlap
8 was not only unavoidable, but desireable. The data reduction
9 techniques as described in the paper by Trombka et al⁽¹³⁾ was already
10 under investigation by the GSFC team and its development has since been
11 progressing. At the same time the USGS team had been using a different
12 data reduction technique for x-ray fluorescence spectra⁽⁴⁾ which also
13 appeared applicable to neutron capture gamma-ray analysis after some
14 minor changes and alterations in the computer program. Tests of this
15 method of data reduction is currently in progress.

16 The technique consists of (1) taking the spectrum of an element to
17 be analyzed; (2) taking spectra of many substances that would interfere,
18 if present, with analysis for the element sought; (3) computing a
19 weighting function to minimize effects of the various interferences;
20 and (4) applying the weighting function to spectra of unknown
21 materials to obtain a figure of merit for each material, indicative of
22 the extent to which it contains the element sought. The technique is
23 novel in that the weighting function is computed without specific
24 knowledge of the unknown material; all that is required is that
25 interfering elements that it contains be represented in step (2)

1 above, but not necessarily at the same concentration level. The
2 weighting function can be made quite general without undue loss of
3 sensitivity, and once it has been computed it can be used for prompt
4 spectral interpretation with computers of very limited capacity or
5 even with programmable electronic calculators. Concurrent determina-
6 tion of a dozen or so elements, using a precomputed weighting function
7 for each, is quite feasible with 1 K of computer memory. The single
8 numerical output for each element permits convenient recording by strip
9 chart or contouring.

10 A first test of the linear combination technique using this
11 system and capture gamma-ray analysis has been completed. Calcium,
12 one of the more difficult elements to measure by the capture gamma-ray
13 method, has arbitrarily been chosen as the element sought. Six 72-keV-
14 wide "windows" containing the more important calcium peaks, are
15 examined for spectra of calcium (CaCO_3) and of ten other elements or
16 compounds having peaks within at least one of the six windows. The
17 weighting functions have been computed for several different groupings
18 of raw data and for counting times of 4-1/2 hours and of 17 minutes.
19 Tests of the weighting function against the various interferences,
20 notably titanium, indicate the ability to discriminate between calcium
21 and individual interferences in ratios of from 1 in 41 to 1 in several
22 hundred; between calcium and an aggregate of all interferences, calcium
23 can be discriminated in a ratio of 1 in 12. Compared with two popular
24 methods of peak area integration, the linear combination technique was
25 much better at rejecting interferences. For analysis involving

1 mixtures of unknown composition, the technique offers improved
2 sensitivity. Details of the method are in press⁽¹⁰⁾.

3 INTERNAL MODERATION

4
5 Most laboratory experiments are performed with a moderator
6 external to the sample. An alternative method which is more applicable
7 to planetary exploration is to use internal moderation, i.e. placement
8 of the isotopic neutron source within the sample. To demonstrate the
9 feasibility of using this technique, the effect of moderation in dry
10 and water-saturated samples was tested in the following manner. An
11 annular-shaped sample holder containing about 25 lbs. of rock sample
12 was buried flush with the surface of the ground which was in a water
13 saturated condition. The detector was placed about 2 feet away on the
14 surface and the californium source (125 μ g) dropped into the center of
15 the annulus (see Figure 7). Figure 8 shows a spectrum taken with the
16 sample holder filled with both dry and wet gold ore. Although water
17 is a good moderator, the spectrum with the higher counting rate was
18 obtained with the dry sample. Because of the high scattering cross-
19 section of hydrogen, many of the high energy neutrons which passed
20 through the sample were scattered in the water saturated ground and
21 were thus returned to the sample at near thermal energies and captured.
22 In this configuration many of the γ rays originated in the outer part
23 of the annularly shaped sample. The sample was then saturated with
24 water and rerun. The total number of spectral counts was depressed as
25 shown in the figure. Although more neutrons were thermalized within

^{252}Cf SOURCE $\text{Ge}(\text{Li})$ DETECTOR EXPERIMENT CONFIGURATION.

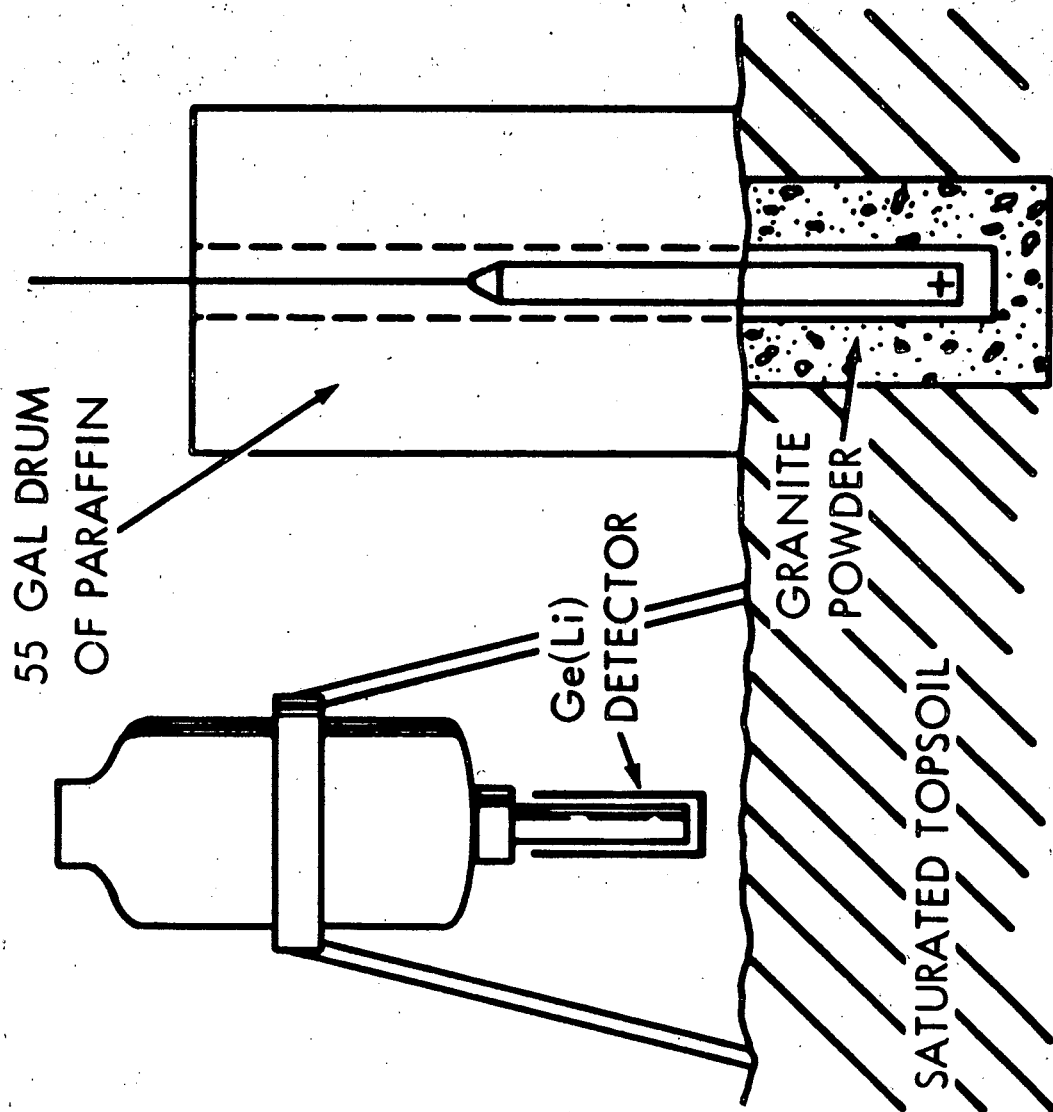


Figure 7

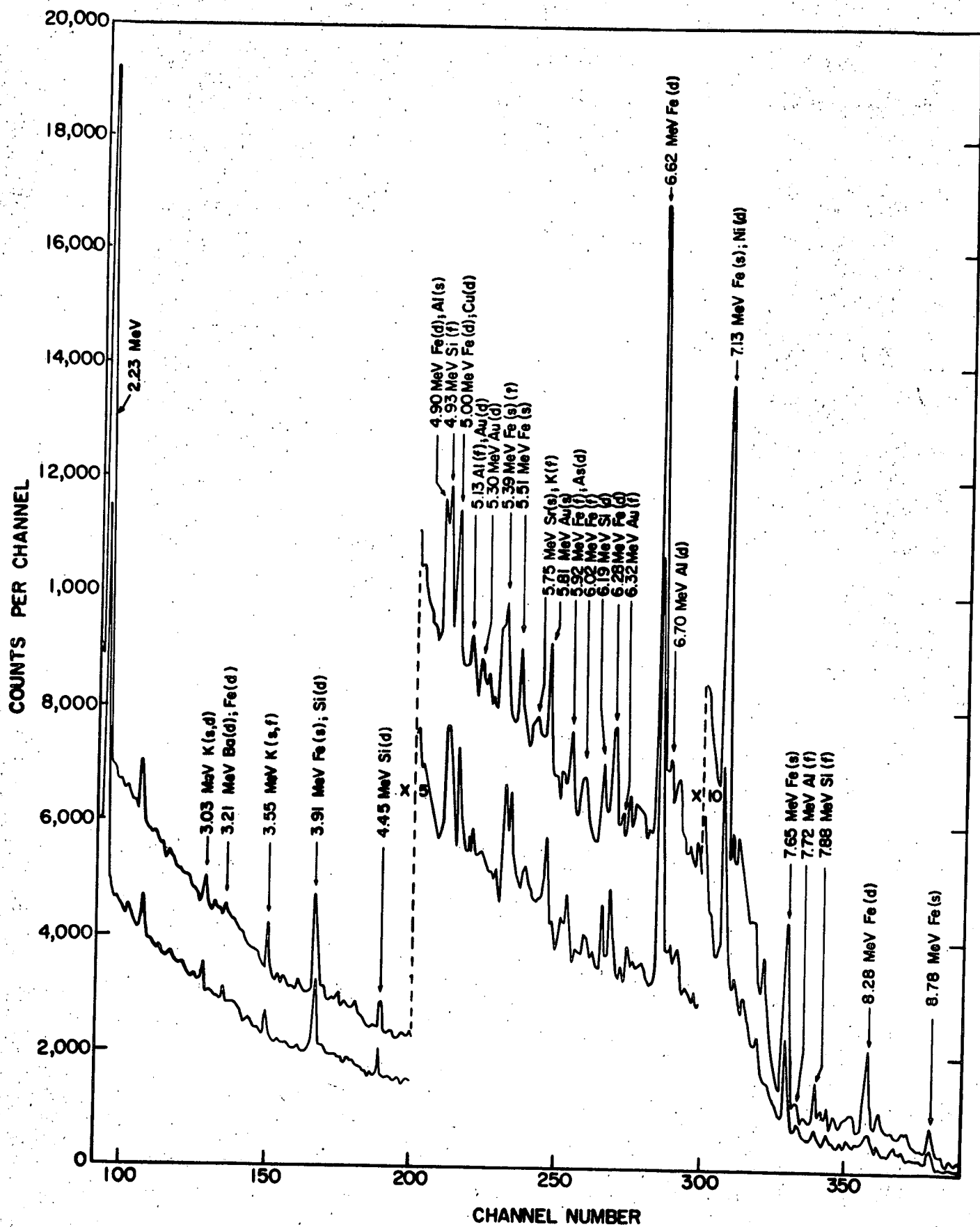


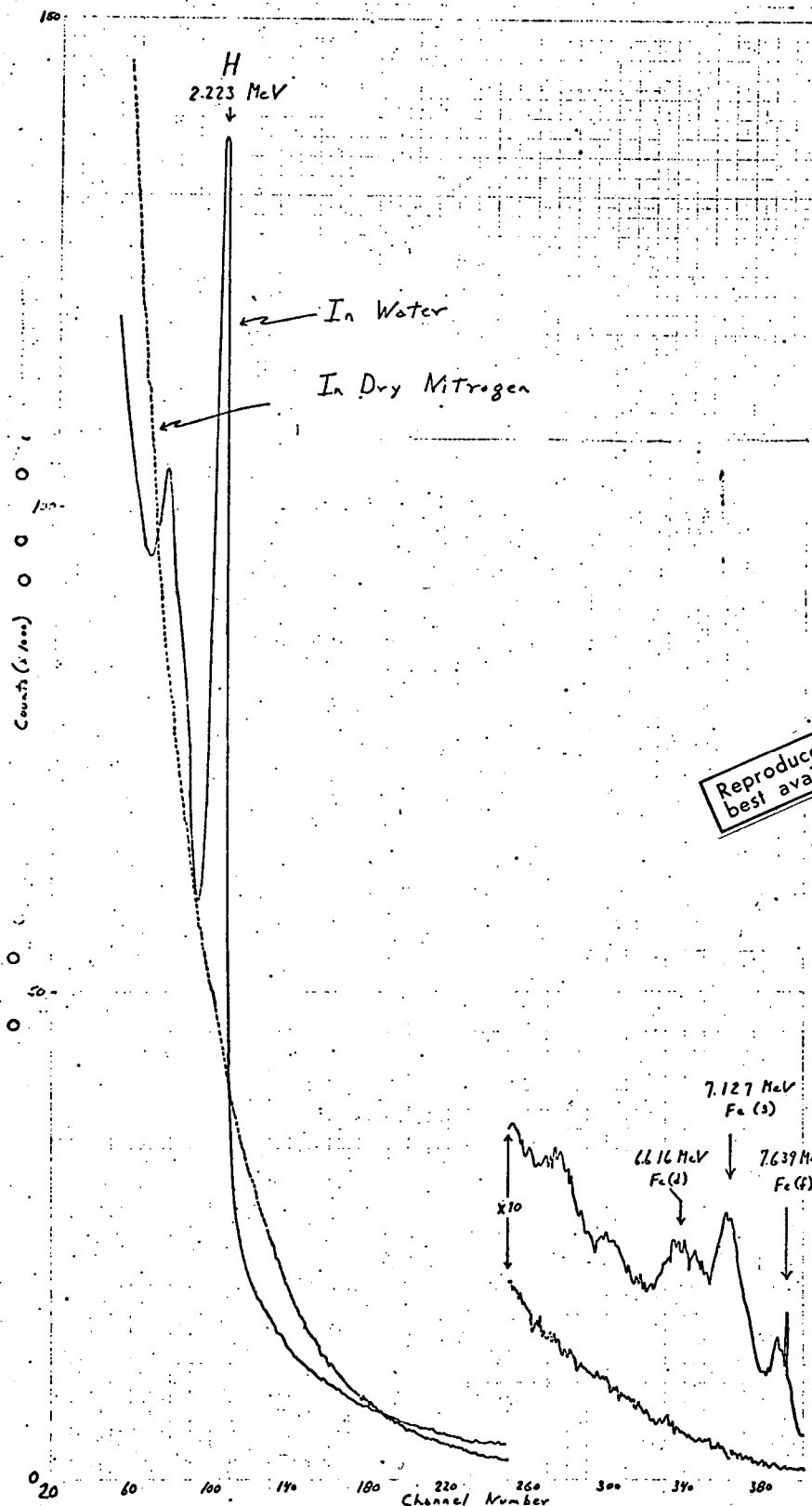
Figure 8

1 the sample, the total number was not as large as the number scattered
2 into the dry sample by the external water as shown by the previous
3 measurement.

4 This is an interesting result which is not obvious when working
5 with small samples in the laboratory. For planetary application it
6 would be best to eliminate an external moderator from the point of view
7 of weight. The question arises as to whether or not sufficient modera-
8 tion can be obtained in a sample without the presence of hydrogen.

9 Figure 9 shows a comparison of two spectra of a one pound iron
10 ring (3-1/2" pipe coupling, I.D. = 5") with a 1 μgm ^{252}Cf source placed
11 inside taken with a NaI(Tl) detector at a distance of 15". A reason-
12 ably good spectrum showing the full, single and double escape peaks of
13 iron is observed when the assembly was immersed in water (solid line).
14 However, the iron lines have all but dissappeared when the measurements
15 were made in dry nitrogen (dashed line).

16 When approximately the same amount of Fe_2O_3 was placed in a thin
17 walled aluminum cylinder (2" diameter, 6.75" long) immersed in water a
18 spectrum similar to the solid line in Figure 9 was obtained. When the
19 same cylinder of Fe_2O_3 was then immersed in CO_2 at one atmosphere of
20 pressure, the single escape peak of iron was just barely visible. The
21 Fe_2O_3 was then mixed with Al_2O_3 to provide additional low mass scatter-
22 ing matrix. This mixture was then made up into a cylinder of the same
23 height but 6.5 inches in diameter and weighed 7 lbs. When this second
24 cylinder was immersed in an atmosphere of CO_2 , the spectrum was
25 essentially a continuum and was devoid of iron peaks. The importance



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Figure 9

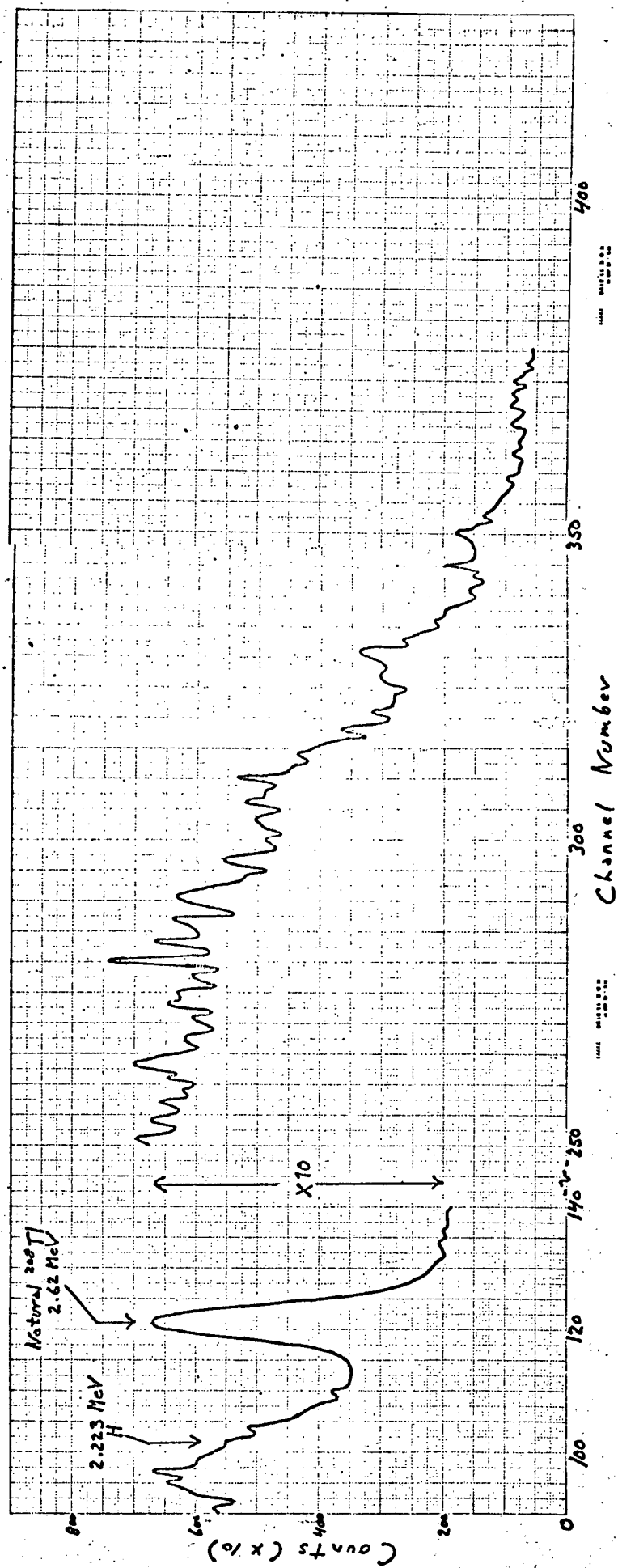


Figure 10

1 of the presence of hydrogen is clear. For relatively small samples one
2 must have hydrogen present to perform any serious spectral analysis.

3 We then ask if one had a semi-infinite sample would the high
4 energy neutrons be slowed down sufficiently for capture and in a small
5 enough volume to obtain a measurable spectrum? Large non-hydrogeneous
6 samples are not easily available and hence an ideal experiment could
7 not be made. However, a barrel of very dry heavy mineral sand
8 concentrate (magnetite, monazite, rutile) was available which could be
9 used to approximate the situation. The 1 μgm ^{252}Cf source was buried
10 about 6-8 inches below the surface. The NaI(Tl) detector was placed
11 beneath the barrel so that there was 20 inches of high density
12 material between the source and detector. The spectrum in Figure 10
13 was obtained. The hydrogen peak is barely visible. Although the ore
14 was quite dry some hydrogen was obviously present. The large peak at
15 2.02 MeV is due to ^{208}Tl , a decay product of thorium in the monazite.
16 The iron peaks are visible but poorly developed. The data again
17 indicate that if there is no hydrogen present one can expect but poor
18 capture gamma ray spectra. It is planned to repeat the latter
19 experiments on more extensive samples which would more properly
20 represent a planetary surface. However, it is felt that the above
21 experiments point out a serious difficulty in obtaining good radiative
22 capture gamma ray spectra on the lunar or planetary surfaces.

23 Some experiments were performed in which the ^{252}Cf source was
24 surrounded with an inch or more of plastic as an external moderator.
25 The plastic shrowded source and the iron ring described above were

1 buried several inches deep in a large barrel of very dry fire clay.
2 The resulting spectrum was exceedingly poor and the iron lines were
3 barely visible. The use of an external moderator is certainly an
4 improvement but more moderator and a better geometrical arrangement
5- will be required to make its use on a planetary mission a feasible
6 procedure.

7 CONCLUSIONS

8
9 Either a radiative capture or a delayed gamma ray method can be
10- used for elemental detection and analysis. Theoretical calculations
11 have been made to show which method is most sensitive for a given
12 element. As the radiative capture method using a ^{252}Cf neutron source
13 has not been fully developed, experiments were performed to test this
14 technique using a ^{252}Cf source. The various causes of interferences
15- have been evaluated and where possible, methods of reducing the
16 interference have been investigated. The source-sample-detector
17 geometry is critical to the capture gamma ray method, and optimum
18 geometrical configurations have been examined. For practical use on a
19 planetary lander the ^{252}Cf source will have to be embedded in or laid
20- on the surface. This is most easily done without the use of an
21 external neutron moderator. As there will be many cases where there
22 will be essentially no hydrogen present experiments were made in
23 relatively dry materials to determine the effects on the spectrum.
24 With a point source of neutrons it was found virtually impossible to
25- get good capture gamma ray spectra. As the delayed gamma ray spectra

1 also depend on thermal neutron capture, it is doubtful whether either
2 technique using a point source of neutrons can be used for planetary
3 elementary analysis. Use of an external moderator will help but it is
4 our experience that sufficient moderator to slow down the required
5- number of neutrons will be too heavy and thus impractical.

6 Some hope lies in the utilization of a distributed source.
7 Experiments in a dry environment with multiple sources are planned and
8 will be carried out during the coming months.
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